

# NON LEPTONIC TWO BODY DECAYS OF $B$ MESONS\*

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## ABSTRACT

Within the framework of the factorization approximation, two body non-leptonic decays of  $B$  mesons are related to semileptonic matrix elements and form factors, evaluated with an effective lagrangian incorporating both chiral and heavy quark symmetries. Using semileptonic  $D$ -decay data, estimates for nonleptonic processes are obtained.

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# 1 Introduction

Nonleptonic decays of heavy mesons give us the possibility of exploring the most interesting and difficult aspects of QCD, in fact nonleptonic processes are complicated by hard gluon exchanges between the hadronizing quarks, quark rearrangement and long range effects. The usual assumption is to use operator product expansion and incorporate long range QCD effects in the hadronic matrix element of local four quark operators. The calculation makes use of an effective  $\Delta B = 1$  hamiltonian [1]:

$$H_{NL} = \frac{G_F}{\sqrt{2}} \left[ V_{ub} V_{uq}^* (c_1 O_1^u + c_2 O_2^u) + V_{cb} V_{cq}^* (c_1 O_1^c + c_2 O_2^c) + V_{tb} V_{tq}^* \sum_{i=3}^6 c_i O_i \right] + h.c. \quad (1.1)$$

where  $q = d, s$ ;  $c_i$  are the Wilson coefficients that take into account the evolution from the scale of the  $W$  to the scale  $\mu$  of the process under consideration;  $O_1^{u,c}$ ,  $O_2^{u,c}$  are the operators:

$$\begin{aligned} O_1^u &= (\bar{u}b)_{V-A} (\bar{q}u)_{V-A} & O_1^c &= (\bar{c}b)_{V-A} (\bar{q}c)_{V-A} \\ O_2^u &= (\bar{q}b)_{V-A} (\bar{u}u)_{V-A} & O_2^c &= (\bar{q}b)_{V-A} (\bar{c}c)_{V-A} \end{aligned} \quad (1.2)$$

$O_i$  ( $i = 3, \dots, 6$ ) are the so-called penguin operators. In the previous formulae  $q = d, s$  and  $(\bar{u}b)_{V-A} = \bar{u}\gamma^\mu(1 - \gamma_5)b$ . Using factorization and discarding colored current operators enables one to write the four quark operators in term of more easily calculable products of current operators, with a coefficient  $a_i$  replacing the Wilson coefficient  $c_i$ . The link among  $a_i$  and  $c_i$  is given, for example for  $i = 1$ , by  $a_1 = c_1 + c_2/N_c$  where the term containing  $c_2$  comes from the Fierz reordering of  $O_2$ , with the color octet term arising from this transformation discarded. However, as discussed by [2] and [3], the rule of discarding the operators with colored currents while applying the vacuum saturation is ambiguous and unjustified. This is a reason, among many others, to make the choice [2], [4] to treat  $a_1$  and the analogous parameter  $a_2$ , multiplying  $O_2$  as free parameters. Let us recall that the analysis of  $D$  non leptonic decays leads to the empirical finding  $a_1 \approx c_1$ ,  $a_2 \approx c_2$  [2]. There has been some recent theoretical effort to understand the empirical rule of “discarding the  $1/N_c$  term”, but these analyses are not conclusive and apply to particular cases and specific kinematics. So it should not be surprising that  $a_i$  values obtained from a fit turn out to be different from those expected naively. On the other hand one should always keep in mind that an “effective approach” such as that proposed in the following, that is factorization with  $a_i$  coefficients fitted from data, is only a first exploratory attempt and numbers obtained in this way should be trusted in most cases only as order of magnitude estimates.

# 2 Semileptonic form factors

The idea behind the factorization approximation is that hadronization appears only after the amplitude takes the form of a product of matrix elements of quark currents which are singlets in color, thus allowing for approximate deductions from semileptonic processes. Different kinematical situations may suggest that factorization may apply better to some non leptonic processes rather than to others. For instance one intuitively expects that it may work better when a color singlet current directly produces an energetic meson easily escaping interaction

with the other quarks. Independently of this, various other effects such as more or less strong role of long-distance contributions, including final state interactions effects, of small annihilation terms, more or less sensitivity to choice of the scale, etc., may suggest that the simultaneous application of the factorization approximation to different processes must be subject to detailed qualifications. Unfortunately at the present stage of the subject one is forced to first collect informations by comparing a very rough procedure to the available data.

According to what already said, in the factorization approximation, two body non leptonic decays of  $B$  and  $B_s$  mesons are obtained by the semileptonic matrix elements of the weak currents between different mesons. A suitable form is

$$\langle P(p')|V^\mu|B(p)\rangle = [(p+p')^\mu + \frac{M_P^2 - M_B^2}{q^2}q^\mu]F_1(q^2) - \frac{M_P^2 - M_B^2}{q^2}q^\mu F_0(q^2) \quad (2.1)$$

$$\begin{aligned} \langle V(\epsilon, p')|(-V^\mu - A^\mu)|B(p)\rangle &= \frac{2V(q^2)}{M_B + M_V}\epsilon^{\mu\nu\alpha\beta}\epsilon_\nu^* p_\alpha p'_\beta \\ &+ i(M_B + M_V)\left[\epsilon_\mu^* - \frac{\epsilon^* \cdot q}{q^2}q_\mu\right]A_1(q^2) \\ &- i\frac{\epsilon^* \cdot q}{(M_B + M_V)}\left[(p+p')_\mu - \frac{M_B^2 - M_V^2}{q^2}q_\mu\right]A_2(q^2) \\ &+ i\epsilon^* \cdot q\frac{2M_V}{q^2}q_\mu A_0(q^2) \end{aligned} \quad (2.2)$$

where  $P$  is a light pseudoscalar meson and  $V$  a light vector meson,  $q = p - p'$ ,

$$A_0(0) = \frac{M_V - M_B}{2M_V}A_2(0) + \frac{M_V + M_B}{2M_V}A_1(0) \quad (2.3)$$

and  $F_1(0) = F_0(0)$ .

For the  $q^2$  dependence of all the form factors we have assumed a simple pole formula  $F(q^2) = F(0)/(1 - q^2/M_P^2)$  with the pole mass  $M_P$  given by the lowest lying meson with the appropriate quantum numbers ( $J^P = 0^+$  for  $F_0$ ,  $1^-$  for  $F_1$  and  $V$ ,  $1^+$  for  $A_1$  and  $A_2$ ,  $0^-$  for  $A_0$ ). The values of the form factors at  $q^2 = 0$ , are given by the study of the semileptonic decays as performed in [5]. For the numerical values of the form factors and of the pole masses used in this calculation we refer the reader to [6].

### 3 Numerical results

Let us evaluate the coefficient  $a_1$ . At present, with data nowadays available, the best way to determine it, is to consider  $\bar{B}^0$  decays into  $D^{*+}\pi^-$ ,  $D^{*+}\rho^-$ ,  $D^+\pi^-$ ,  $D^+\rho^-$  final states. In order to use the experimental data we need an input for current matrix elements between  $B$  and  $D$ ,  $D^*$  states.

In [5] we did not consider  $B \rightarrow D$  and  $B \rightarrow D^*$  transitions in the heavy quark effective theory; this subject has been investigated by several authors and we rely on their work to compute the corresponding non leptonic decay rates. The relevant matrix elements at leading order in  $1/M_Q$  are [7]

$$\langle D(v')|V^\mu(0)|B(v)\rangle = \sqrt{M_B M_D}\xi(w)[v + v']^\mu \quad (3.1)$$

$$\begin{aligned}
& < D^*(\epsilon, v') | (V^\mu - A^\mu) | B(v) > = \\
& \sqrt{M_B M_D} \xi(w) \left[ -\epsilon^{\mu\lambda\rho\tau} \epsilon_\lambda^* v_\rho v'_\tau + i(1 + v \cdot v') \epsilon^{*\mu} - i(\epsilon^* \cdot v) v'^\mu \right]
\end{aligned} \tag{3.2}$$

where  $w = v \cdot v' = (M_B^2 + M_D^2 - q^2)/2M_B M_D$ ,  $v$  and  $v'$  are the meson velocities, and  $\xi(w)$  is the Isgur-Wise form factor.  $\xi(w)$  has been computed by QCD sum rules [8], [9], potential models, and estimated phenomenologically [4]. We shall take for it the expression [10]

$$\xi(w) = \left( \frac{2}{1+w} \right) \exp \left[ -(2\rho^2 - 1) \frac{w-1}{w+1} \right] \tag{3.3}$$

which reproduces rather well the semileptonic data [11] with  $\rho \simeq 1.19$ ,  $V_{cb} = 0.04$ ,  $\tau_B = 1.4 ps$ . We stress that we have chosen to work at the leading order in  $1/M_Q$ , which is why we have not introduced the non leading form factors discussed e.g. in [12], [13].

From the new CLEO data [14]  $BR(\bar{B}^0 \rightarrow D^+ \pi^-) = (2.2 \pm 0.5) \times 10^{-3}$ ,  $BR(\bar{B}^0 \rightarrow D^{*+} \pi^-) = (2.7 \pm 0.6) \times 10^{-3}$ ,  $BR(\bar{B}^0 \rightarrow D^+ \rho^-) = (6.2 \pm 1.4) \times 10^{-3}$  and  $BR(\bar{B}^0 \rightarrow D^{*+} \rho^-) = (7.4 \pm 1.8) \times 10^{-3}$  one gets

$$|a_1| \simeq 1.0 \tag{3.4}$$

Let us consider now a class of decays that depend only on the parameter  $a_2$ . Recent data from CLEO Collaboration [14] allow for a determination of this parameter. From  $BR(B \rightarrow K J/\psi) = (0.10 \pm 0.016) \times 10^{-2}$ ,  $BR(B \rightarrow K^* J/\psi) = (0.19 \pm 0.036) \times 10^{-2}$  and  $BR(B \rightarrow K \psi(2s)) = (0.10 \pm 0.036) \times 10^{-2}$  we obtain

$$|a_2| \simeq 0.27 \tag{3.5}$$

We have now to determine the relative sign between  $a_1$  and  $a_2$ . The new CLEO data [14]  $BR(B^- \rightarrow D^0 \pi^-) = (4.7 \pm 0.6) \times 10^{-3}$ ,  $BR(B^- \rightarrow D^{*0} \pi^-) = (5.0 \pm 1.0) \times 10^{-3}$ ,  $BR(B^- \rightarrow D^0 \rho^-) = (10.7 \pm 1.9) \times 10^{-3}$  and  $BR(B^- \rightarrow D^{*0} \rho^-) = (14.1 \pm 3.7) \times 10^{-3}$ , allow to conclude that the ratio  $a_2/a_1$  is positive. Clearly this result depends on the relative phase of the hadronic matrix elements. We assume (analogously to [2]) that for a decay  $B \rightarrow M_1 M_2$  ( $M_1$  and  $M_2$  scalar or vector mesons) the phase among the two products of matrix elements in the factorization approximation is the one determined under the assumption of spin and flavour symmetry in the meson spectrum. Of course these symmetries are (even badly) broken in many decays; one should therefore be aware of the possibility to have a different phase between the two terms in such cases.

We now come to our numerical results. For the values of  $f_P$  and  $f_V$  used in computing the rates we refer to the values and the discussion in [6].

Let us now consider some example of branching ratios obtained in this framework. For a more exhaustive list see [6]. Let us stress that the quoted errors refer only to the experimental input regarding semileptonic form factors. The theoretical uncertainty is difficult to evaluate and in general we should regard these numbers only as a first estimate.

Table 1: *Predicted widths and branching ratios for  $\bar{B}^0$  decays. We use  $\tau_{\bar{B}^0} = 14 \times 10^{-13}s$ ,  $V_{ub} = 0.003$ ,  $V_{cb} = 0.04$ . The quoted errors come from the uncertainties on the form factors. Theoretical errors are not included.*

Process	$\Gamma$ in $10^{12}s^{-1}$	Br
$\pi^+ \pi^-$	$1.5a_1^2  V_{ub}V_{ud}^* ^2$	$(1.8 \pm 0.8) \times 10^{-5}$
$\pi^+ \rho^-$	$4.0a_1^2  V_{ub}V_{ud}^* ^2$	$(4.8 \pm 2.9) \times 10^{-5}$
$\rho^+ \pi^-$	$0.3a_1^2  V_{ub}V_{ud}^* ^2$	$(3.6 \pm 7.3) \times 10^{-6}$
$\rho^+ \rho^-$	$1.1a_1^2  V_{ub}V_{ud}^* ^2$	$(1.3 \pm 2.1) \times 10^{-5}$
$\pi^+ \bar{D}_s^-$	$6.8a_1^2  V_{ub}V_{cs}^* ^2$	$(8.1 \pm 3.6) \times 10^{-5}$
$\pi^+ D_s^{*-}$	$5.1a_1^2  V_{ub}V_{cs}^* ^2$	$(6.1 \pm 2.6) \times 10^{-5}$
$\rho^+ \bar{D}_s^-$	$1.0a_1^2  V_{ub}V_{cs}^* ^2$	$(1.2 \pm 2.4) \times 10^{-5}$
$\rho^+ D_s^{*-}$	$3.8a_1^2  V_{ub}V_{cs}^* ^2$	$(4.5 \pm 2.9) \times 10^{-5}$
$\pi^+ D^-$	$5.4a_1^2  V_{ub}V_{cd}^* ^2$	$(3.3 \pm 1.5) \times 10^{-6}$
$\pi^+ D^{*-}$	$4.0a_1^2  V_{ub}V_{cd}^* ^2$	$(2.5 \pm 1.1) \times 10^{-6}$
$\rho^+ D^-$	$0.8a_1^2  V_{ub}V_{cd}^* ^2$	$(4.9 \pm 9.8) \times 10^{-7}$
$\rho^+ D^{*-}$	$2.8a_1^2  V_{ub}V_{cd}^* ^2$	$(1.7 \pm 1.2) \times 10^{-6}$
$K^0 J/\psi$	$7.1a_2^2  V_{cb}V_{cs}^* ^2$	$(1.1 \pm 0.6) \times 10^{-3}$
$K^0 \psi(2s)$	$2.4a_2^2  V_{cb}V_{cs}^* ^2$	$(0.37 \pm 0.19) \times 10^{-3}$
$K^{*0} J/\psi$	$10.4a_2^2  V_{cb}V_{cs}^* ^2$	$(1.6 \pm 0.5) \times 10^{-3}$
$K^{*0} \psi(2s)$	$4.8a_2^2  V_{cb}V_{cs}^* ^2$	$(0.74 \pm 0.23) \times 10^{-3}$
$\pi^0 D^0$	$2.6a_2^2  V_{cb}V_{ud}^* ^2$	$(4.1 \pm 1.8) \times 10^{-4}$
$\pi^0 D^{*0}$	$2.1a_2^2  V_{cb}V_{ud}^* ^2$	$(3.3 \pm 1.4) \times 10^{-4}$
$\eta D^0$	$0.7a_2^2  V_{cb}V_{ud}^* ^2$	$(1.1 \pm 0.5) \times 10^{-4}$
$\eta D^{*0}$	$0.5a_2^2  V_{cb}V_{ud}^* ^2$	$(8.6 \pm 4.2) \times 10^{-5}$
$\rho^0 D^0$	$0.4a_2^2  V_{cb}V_{ud}^* ^2$	$(6.1 \pm 12.2) \times 10^{-5}$
$\rho^0 D^{*0}$	$1.4a_2^2  V_{cb}V_{ud}^* ^2$	$(2.2 \pm 1.4) \times 10^{-4}$
$K^0 \bar{D}^0$	$4.4a_2^2  V_{cb}V_{us}^* ^2$	$(3.5 \pm 1.8) \times 10^{-5}$
$K^0 D^{*0}$	$3.4a_2^2  V_{cb}V_{us}^* ^2$	$(2.8 \pm 1.3) \times 10^{-5}$
$K^{*0} D^0$	$0.5a_2^2  V_{cb}V_{us}^* ^2$	$(3.6 \pm 7.1) \times 10^{-6}$
$K^{*0} D^{*0}$	$2.3a_2^2  V_{cb}V_{us}^* ^2$	$(1.9 \pm 1.3) \times 10^{-5}$
$\pi^0 J/\psi$	$4.5a_2^2  V_{cb}V_{cd}^* ^2$	$(3.7 \pm 1.6) \times 10^{-5}$
$\eta J/\psi$	$1.2a_2^2  V_{cb}V_{cd}^* ^2$	$(1.0 \pm 0.4) \times 10^{-5}$
$\rho^0 J/\psi$	$6.7a_2^2  V_{cb}V_{cd}^* ^2$	$(5.3 \pm 1.8) \times 10^{-5}$
$\omega J/\psi$	$6.7a_2^2  V_{cb}V_{cd}^* ^2$	$(5.3 \pm 1.8) \times 10^{-5}$
$\pi^0 \pi^0$	$0.73a_2^2  V_{ub}V_{ud}^* ^2$	$(6.4 \pm 3.2) \times 10^{-7}$
$\eta \eta$	$0.07a_2^2  V_{ub}V_{ud}^* ^2$	$(6.1 \pm 3.0) \times 10^{-8}$
$\pi^0 \rho^0$	$1.6a_2^2  V_{ub}V_{ud}^* ^2$	$(1.4 \pm 0.7) \times 10^{-6}$
$\eta \rho^0$	$0.18a_2^2  V_{ub}V_{ud}^* ^2$	$(1.5 \pm 1.4) \times 10^{-7}$
$\rho^0 \rho^0$	$0.53a_2^2  V_{ub}V_{ud}^* ^2$	$(4.5 \pm 7.0) \times 10^{-7}$
$\pi^0 \omega$	$0.54a_2^2  V_{ub}V_{ud}^* ^2$	$(4.6 \pm 4.3) \times 10^{-7}$

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